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Technical Note N-651

A SIMPLE METHOD FOR CALCULATION OF GAMMA-RAY SHIELDING PROPERTIES OF SHELTER ENTRANCEWAYS

BY

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A SIMPLE METHOD FOR CALCULATION OF GAMMA-RAY

SHIELDING PROPERTIES OF SHELTER ENTRANCEWAYS

Y-F008-08-05-201 (DASA 11.026)

Type C

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ABSTRACT

An empirical equation is described for calculating the attenuation factor for gamma radiation within a ducted entranceway into a shelter. Some sample problems are worked, and a discussion is given of the accuracy of the formula.

This research was funded by the Defense Atomic Support Agency through the Bureau of Yards and Docks under DASA Subtask No. 11.026.

INTRODUCTION

A difficult calculational problem has been that of computing attenuation factors for gamma radiation within a two-legged duct in concrete.[1,2,3] It has been found that the following formula can be used to obtain approximate answers

$$\frac{D}{D_o} = 0.25 \frac{\left(\frac{H}{W}\right)^{0.907} W^{2.864}}{L_1^{2.534} L_2^{2.667} E_o^{0.710}}$$

where

D_o = dose rate in mr/hr outside the shelter

D = dose rate in mr/hr inside the shelter

H = height of entranceway in feet

W = width of entranceway in feet

L_1 = length in feet of first leg of duct

L_2 = length in feet of second leg of duct

E_o = average energy of gamma radiation in Mev

This method of calculation can be used for fallout radiation. It does not consider penetration of radiation through the walls or ceiling of a shelter, but is concerned entirely with that radiation which streams through the shelter entranceway. The formula is valid when the following inequalities are true

$0.662 \leq E_o \leq 3.000$ Mev

$1.0 \leq H \leq 6.0$ feet

$1.0 \leq W \leq 6.0$ feet

$2 \leq L_1 \leq 36$ feet

$1 \leq H/W \leq 2$

$L_1/H \leq 6$

$L_2/H \leq 6$

$L_1/W \leq 2$

$L_2/W \leq 2$

The formula has a safety factor already incorporated into it, so that one can be 95 percent certain that the actual attenuation factor, D/D_o, is at least as small as the attenuation factor calculated by the formula.

USE OF THE FORMULA

The basic formula with which this note is concerned can be written in a slightly simplified version as follows

$$\frac{D}{D_o} = 0.25 \frac{\left(\frac{H}{W}\right)^{0.907} \quad W^{2.864}}{L_1^{2.534} \quad L_2^{2.667}}$$

In this case, the energy term has been omitted. The reason for this simplification is that the mean effective energy of fallout radiation is approximately 1 Mev. Since unity raised to any power is still unity, the energy factor cannot appreciably change the final answer as long as only fallout radiation is considered. (If the higher energies of gamma-ray initial radiation are to be considered, the more complete equation shown in the Introduction must be used.)

Figure 1 shows an example of a two-legged duct leading into a shelter. The dimensions of the duct, as they are normally measured, are shown.

Consider a sample problem:

Calculate the dose rate attenuation provided by a shelter entranceway if the cross section of the duct is 6 feet high by 4 feet wide, the length of the first leg is 12 feet, and the length of the second leg is 14 feet. Assume the effective gamma-ray energy is 1 Mev.

Substitution of the values given above into the simpler version of the empirical formula gives

$$\frac{D}{D_o} = 0.25 \frac{\left(\frac{6}{4}\right)^{.907} \cdot 4^{2.864}}{12^{2.534} \cdot 14^{2.667}}$$

With a log-log sliderule, the above equation can be solved to give

$$\frac{D}{D_o} = 0.25 \frac{(1.445) \quad (53)}{(545) \quad (1130)}$$

$$\frac{D}{D_o} = 3.11 \times 10^{-5}$$

Another way of solving the equation is to use logarithms. The solution is then obtained as follows

$$\log (0.25) = 9.39794 - 10$$

$$\log (1.5^{0.907}) = 0.907 \log 1.5 = 0.907 (0.17609) = 0.15971$$

$$\log (4^{2.864}) = 2.864 \log 4 = 2.864 (0.60206) = 1.72430$$

$$\log (\text{numerator}) = 11.28195 - 10$$

$$\log (12^{2.534}) = 2.534 \log 12 = 2.534 (1.07918) = 2.73464$$

$$\log (14^{2.667}) = 2.667 \log 14 = 2.667 (1.14613) = 3.05673$$

$$\log (\text{denominator}) = 5.79137$$

$$\log (D/D_o) = (11.28195 - 10) - 5.79137$$

$$\log (D/D_o) = 5.49058 - 10$$

$$D/D_o = 3.0945 \times 10^{-5}$$

Still another way to solve the given problem is to use the graphs given in Figures 2, 3, 4, and 5. The same problem is worked as follows:

(1) Note that $H/W = 1.5$. From Figure 2, read $(H/W)^{0.907} = 1.45$. This is the eccentricity factor corresponding to $H/W = 1.5$.

(2) From Figure 2, read the width factor corresponding to $W = 4$ feet. This value is 50.

(3) From Figure 3, read the first leg factor corresponding to $L_1 = 12$ feet. The factor is 500.

(4) From Figure 4, read the second leg factor corresponding to $L_2 = 14$ feet. One obtains 1200.

(5) Multiply the constant factor, 0.25, times the eccentricity factor and the width factor. Then divide by the product of the two leg factors. The answer is found to be

$$\frac{D}{D_o} = 0.25 \frac{1.45 \times 50}{500 \times 1200}$$

$$\frac{D}{D_o} = 3.02 \times 10^{-5}$$

This answer is accurate enough for shielding calculations.

NOMOGRAM

A nomogram has been developed to solve two-legged duct problems, as shown in Figure 6. The sample problem can be solved nomographically.

The data given for the duct dimensions were

$$H = 6 \text{ feet}$$
$$W = 4 \text{ feet}$$
$$L_1 = 12 \text{ feet}$$
$$L_2 = 14 \text{ feet}$$

The value of $H/W = 6/4 = 1.5$ is needed for the nomogram calculation. The solution is obtained as follows:

Draw a straight line from 14 on the L_1 scale to 12 on the L_2 scale. Note where this line intersects the vertical line between the L_1 scale and the L_2 scale.

Next, draw a straight line from 1.5 on the H/W scale to 4 on the W scale. Note where this line intersects the vertical line between the H/W scale and the L_2 scale.

Now, draw a straight line between the two intersection points determined above, and note where this line corsses the D/D_o scale.

Using the nomogram of Figure 6, one obtains for the answer to the sample problem

$$\frac{D}{D_o} = 3.5 \times 10^{-5}$$

Although this method is less accurate than the other methods for solution of the two-legged duct problem, the nomographic technique is still sufficiently accurate for most practical purposes.

SAMPLE PROBLEMS

Twelve sample problems are now given to allow an opportunity for practice with any or all of the three calculational techniques described in the previous section. Duct dimensions in feet are taken to be the following values:

L_1	L_2	H	W
11.	18.	5.2	4.8
16.	17.	4.1	3.0
20.	20.	3.7	2.9
19.	8.	4.2	2.2
29.	25.	5.1	2.6
25.	15.	5.2	4.0
14.	12.	2.9	2.9
30.	16.	5.7	4.1
24.	14.	5.1	3.0
18.	24.	4.5	3.6
8.	14.	3.3	3.0
17.	21.	5.8	5.0

The problems with their answers are shown in Table 1. In case the E-type notation is not familiar, it is explained by the following example:

$$0.4218E\text{-}04 = 0.4218 \times 10^{-4}$$

CONCLUSION

A simple empirical formula has been described for calculating the gamma-ray dose attenuation factor of fallout radiation within a two-legged duct with one right-angle bend. The formula can be used in the field as a guide in the design of entranceways, escape hatches, or air ducts leading into shelters.

ACKNOWLEDGEMENT

The author wishes to express his appreciation to Professor W. C. Ingold of Ventura College, Ventura, California, for his extensive work on the development of the empirical formula. Mr. Y. T. Song and Mr. J. S. Grant of the U. S. Naval Civil Engineering Laboratory were of great assistance in the development of the nomogram.

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1. U. S. Naval Civil Engineering Laboratory. Technical Report R-264: Computer Calculation of Dose Rates in Two-Legged Ducts Using the Albedo Concept, by J. M. Chapman, Port Hueneme, California, October 1963.

2. U. S. Naval Civil Engineering Laboratory. Technical Report R-289: Gamma-Ray Streaming Through Ducts, by C. M. Huddleston and W. L. Wilcoxson, Port Hueneme, California, February 1964.

3. U. S. Naval Civil Engineering Laboratory. Technical Report R-349: An Empirical Formula for the Calculation of Gamma-Ray Dose Attenuation in Concrete Ducts, by W. C. Ingold and C. M. Huddleston, Port Hueneme, California, to be published.

Table 1. Attenuation Factors for Sample Ducts

L_1	L_2	H	W	Attenuation
11.	18.	5.2	4.8	.2476E-04
16.	17.	4.1	3.0	.3586E-05
20.	20.	3.7	2.9	.1126E-05
19.	8.	4.2	2.2	.9648E-05
29.	25.	5.1	2.6	.2616E-06
25.	15.	5.2	4.0	.3520E-05
14.	12.	2.9	2.9	.8705E-05
30.	16.	5.7	4.1	.2129E-05
24.	14.	5.1	3.0	.2625E-05
18.	24.	4.5	3.6	.1648E-05
8.	14.	3.3	3.0	.2862E-04
17.	21.	5.8	5.0	.6515E-05

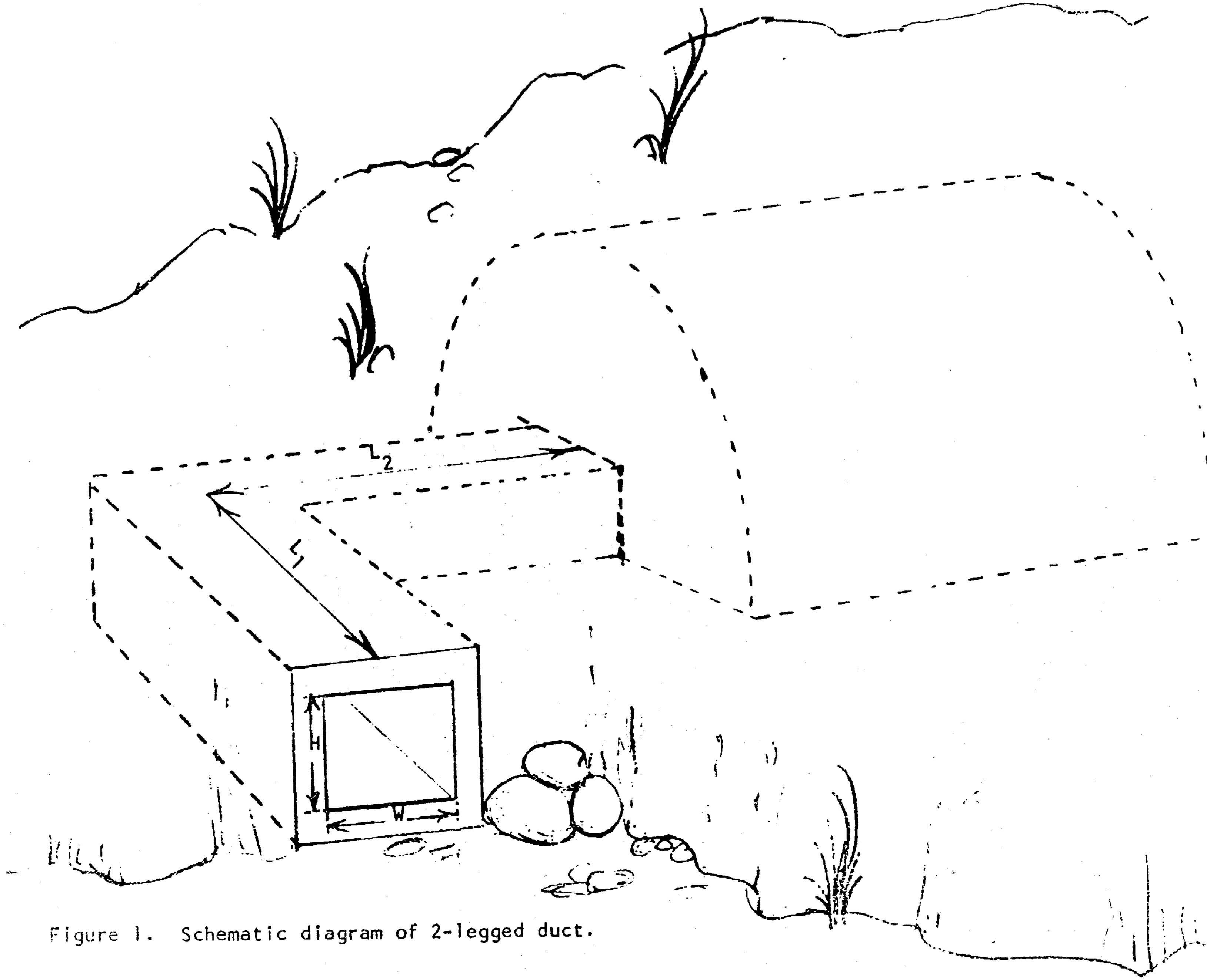

Figure 1. Schematic diagram of 2-legged duct.

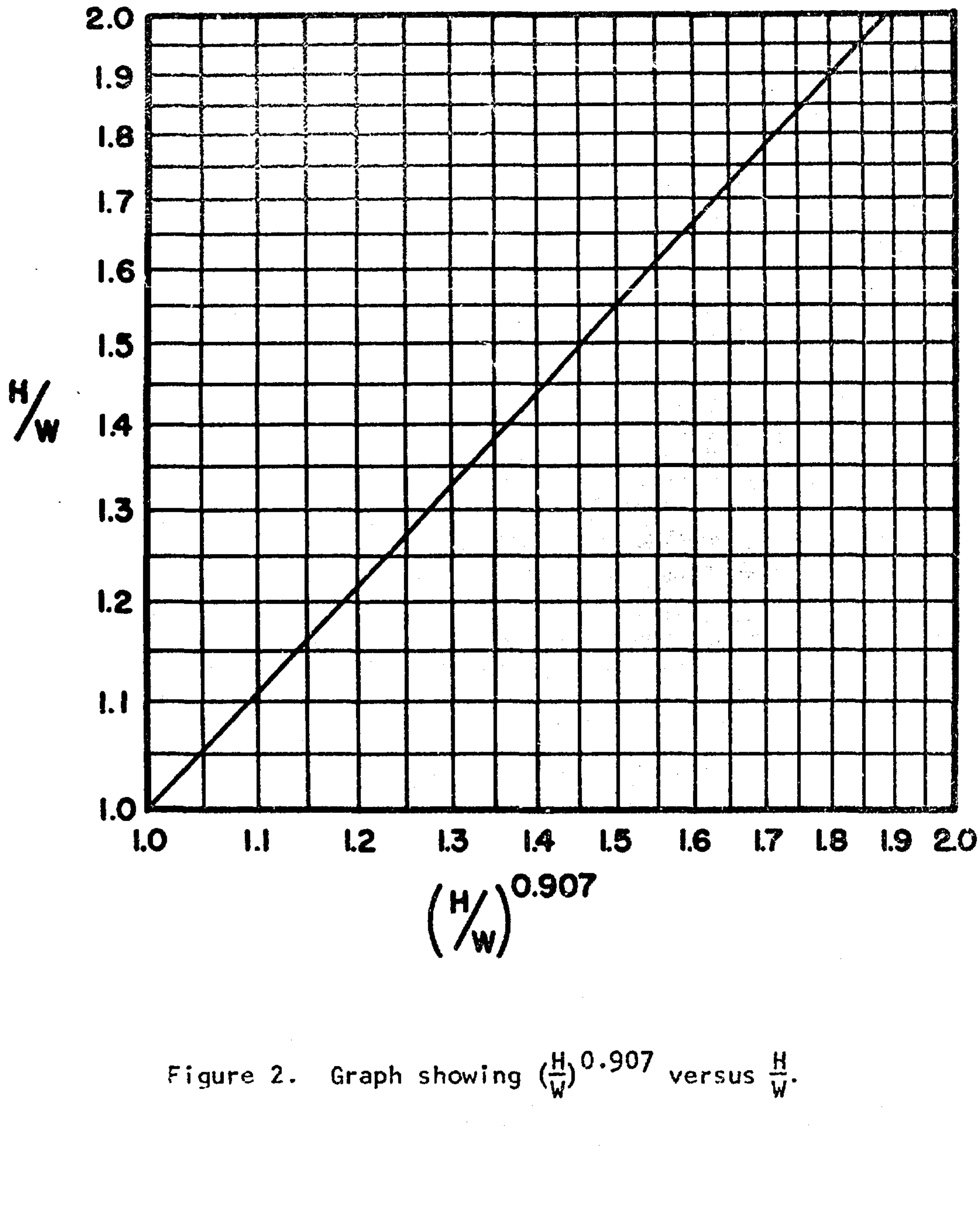

Figure 2. Graph showing $(\frac{H}{W})^{0.907}$ versus $\frac{H}{W}$.

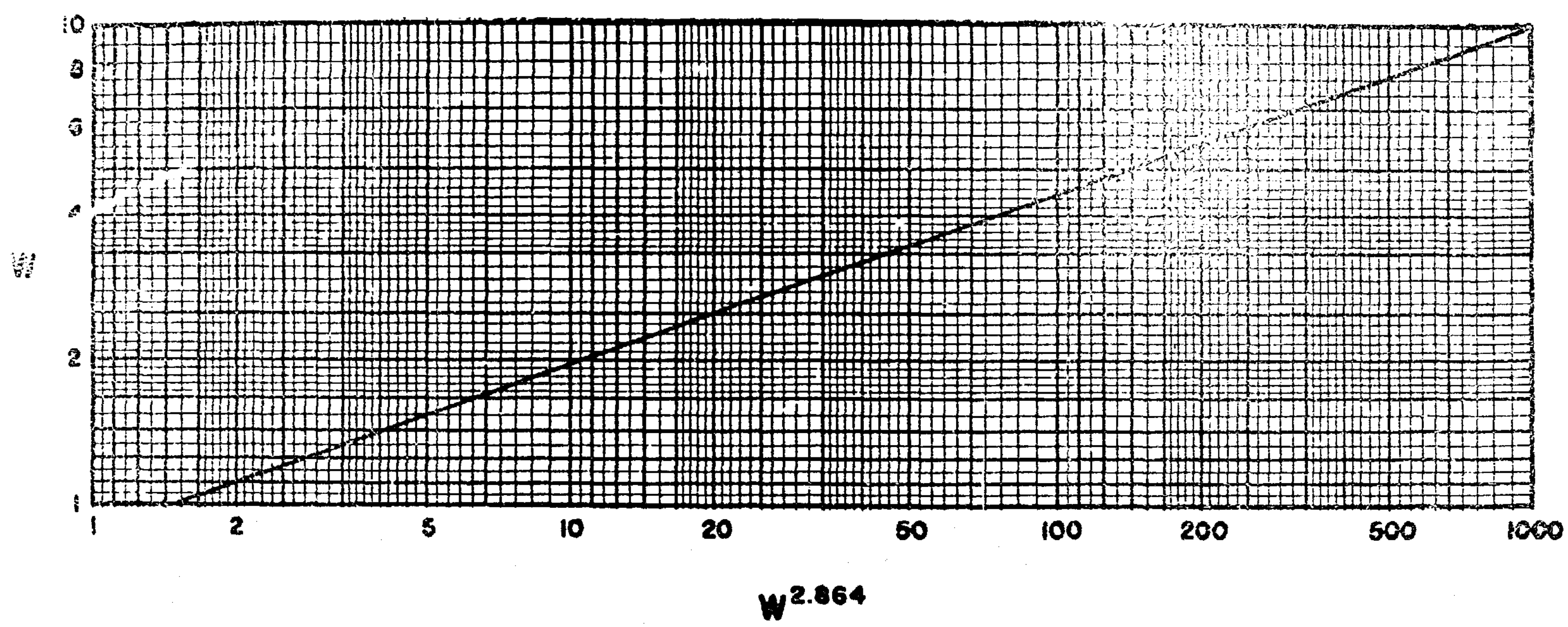

Figure 3. Graph showing $W^{2.864}$ versus W.

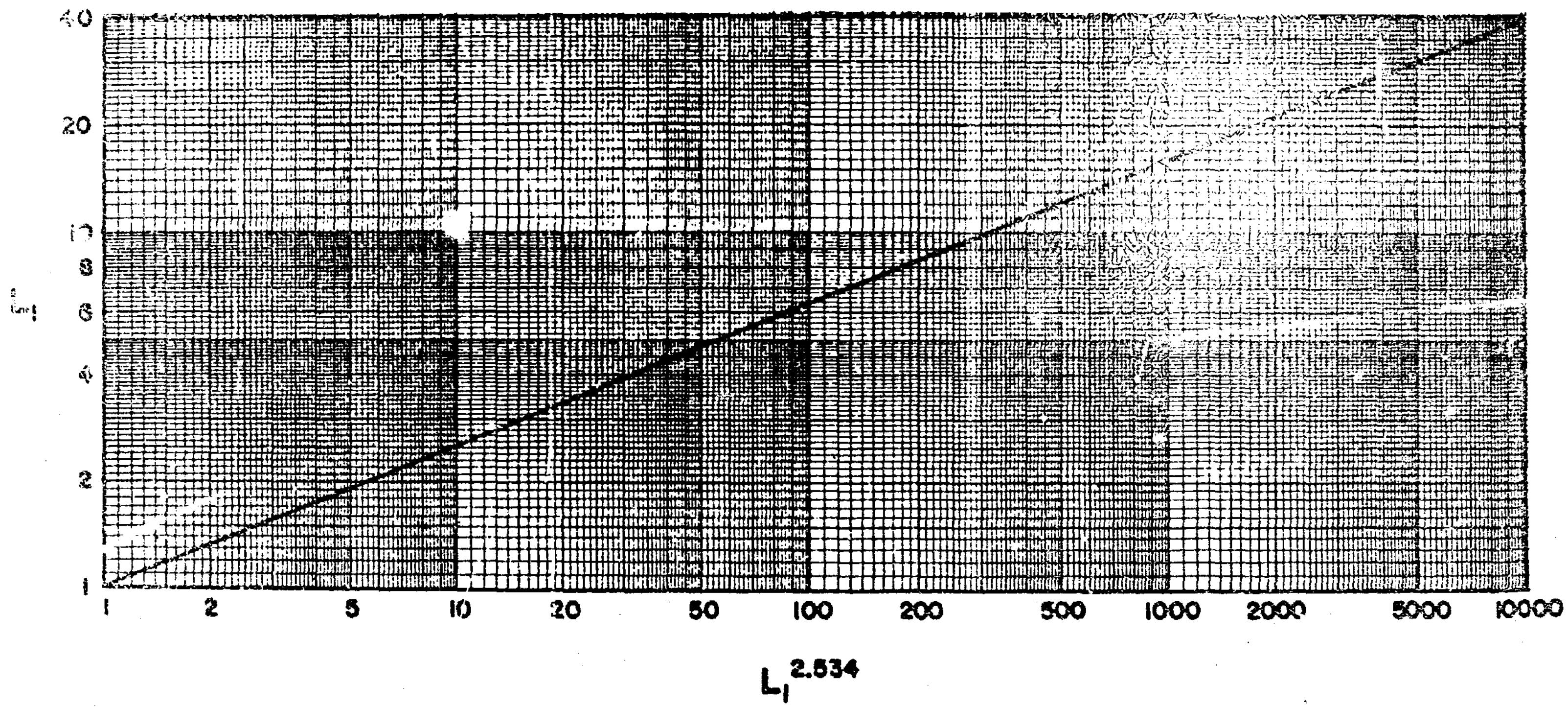

Figure 4. Graph showing $L_1^{2.534}$ versus L_1.

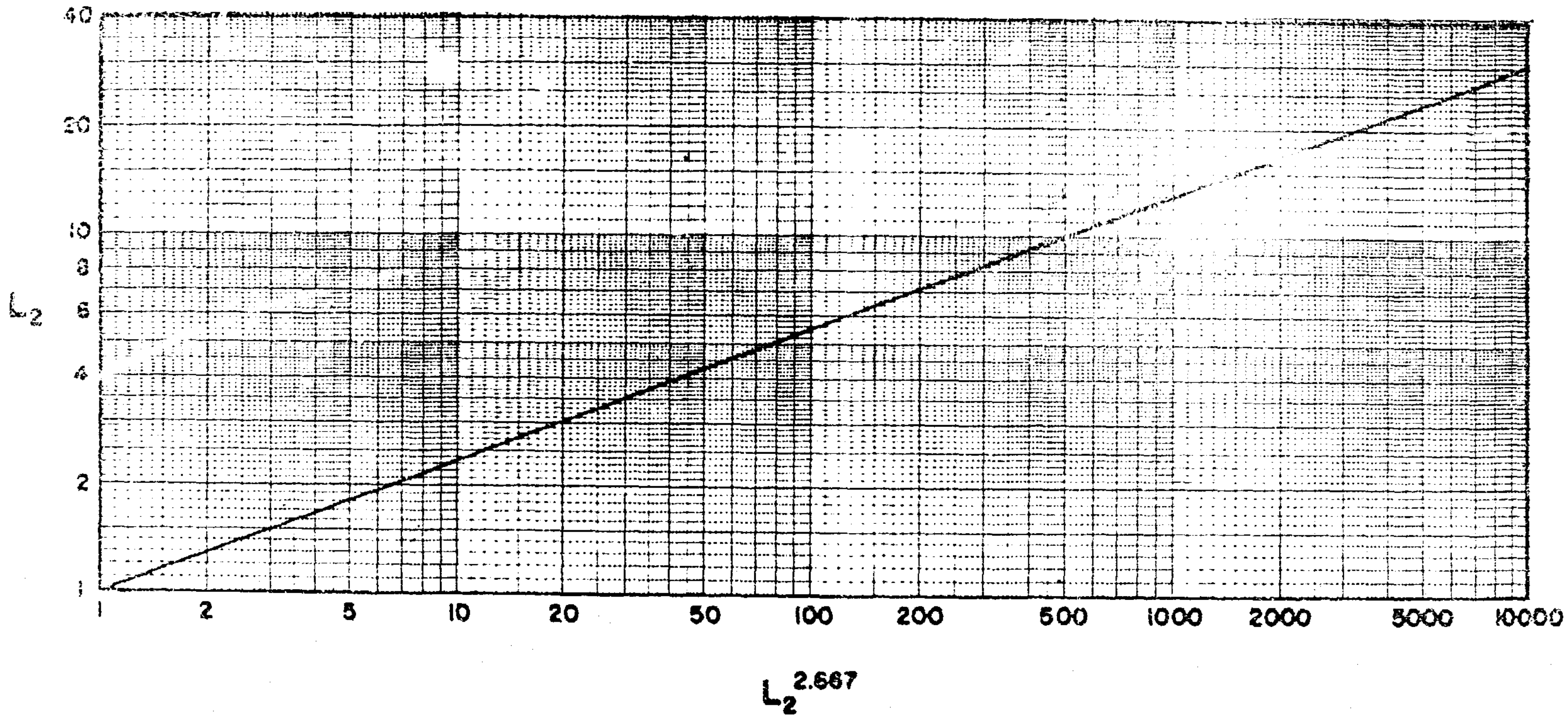

Figure 5. Graph showing $L_2^{2.667}$ versus L_2.

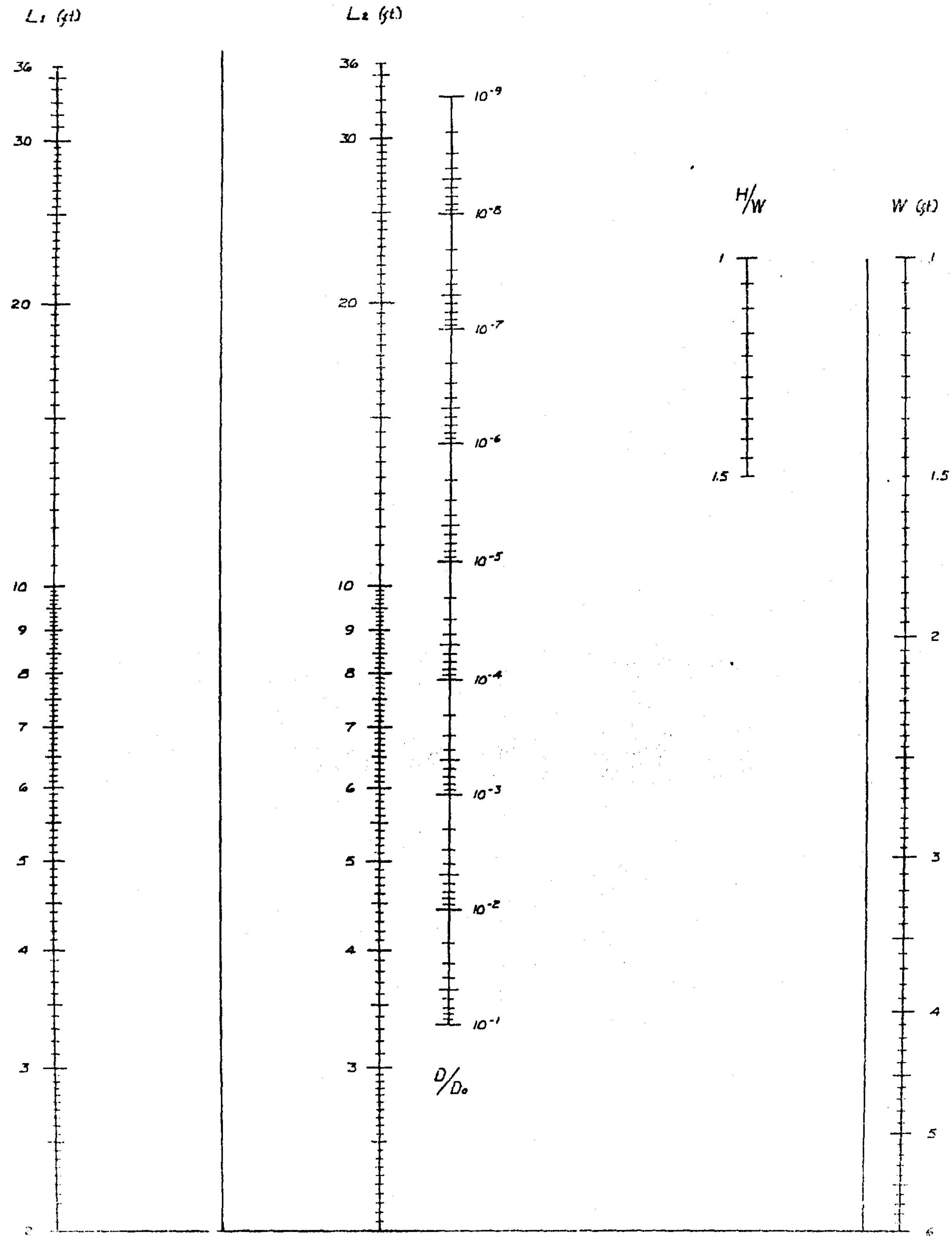

Figure 6. Nomogram for calculating two-legged duct problems.

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